THE EVOLUTION OF CLINICAL SPHYGMOMANOMETRY*

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THE pressure of the blood within its system of circulation has always been one of the major physiological manifestations of health and of disease. Knowledge of the behavior and significance of this pressure was, for long, slowly accumulated; and its development depended upon the evolution of certain techniques. The common clinical method of measuring the blood pressure by a mercury manometer and a stethoscope over an artery is a comparatively recent procedure, in fact more recent than clinical electrocardiography. A few remarks on its evolution may be of interest.

Though the circulation of the blood was established as fact by Harvey in 1628; and the pressure of blood in the circulation was shown in a measurable way by Hales in 1733; and the use of a manometer using fluid, either water or blood and later mercury, was well-known and employed in physiological circles in the latter half of the Nineteenth Century, the clinical technique did not evolve until after the turn of the century, and did not become widely used until thirty years ago. Yet, the art of simple palpation of peripheral arteries has undoubtedly existed as long as the art of medicine; the ancient physician, one can justifiably suppose, made crude but often significant deductions on the tension of the arteries, even before he realized the nature of the circulation of the blood. The exact formulation of such observations awaited the use of instruments of precision and a technique for their application. Janeway[1] expressed aptly this historical point when he wrote, "that the blood exerts pressure upon the vessels through which it circulates is, of course, a necessary corollary of the fact that it flows; but more than a hundred years elapsed before Harvey's discovery of the circulation was followed by Hales' demonstration of the blood pressure in 1733, and a second century before its accurate study was begun."

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My purpose in this paper is the history of the concept of sphygmomanometry and of the introduction of its various techniques into clinical medicine; the development of the instruments has been considered elsewhere.[1,2] There are four techniques for measuring the blood pressure; in historical order they are: the method of palpation, first without, later with, the use of a manometer; the method of direct measurement; the method of recording the oscillations of the pressure; and the method of auscultation.

Simple palpation, without doubt, has been an old natural procedure. It became of more value with the use of a manometer for recording the pressure necessary to obliterate the pulse, of which I shall say more later.

In 1733, Hales[3] introduced the technique of direct mensuration by placing a tube in the artery of an animal and obtaining the height to which the blood flowed, a procedure still employed widely today in modified form and primarily for physiologic investigation. Yet a century elapsed before the accurate study of the blood pressure began, as Janeway pointed out, with the introduction by Poiseuille[4] in 1828 of the device of mercury in a U-tube. This procedure separated the observation of the blood pressure from the difficulties of large and unwieldy apparatus and provided the convenient facilities of a small instrument. Also, with the use of an anti-coagulant substance, sodium carbonate, to keep blood from clotting in tubes, Poiseuille made prolonged experiments possible.

Twenty years later, in 1847, the second major advance in accurate study was initiated by Ludwig[5] with the invention of the kymograph. Its application to indirect measurement of the blood pressure by the use of a pelotte placed over an artery and connected with a manometer and thereby dispensing with puncture of the artery, was suggested in 1855 by Vierordt;[6] but his apparatus was unreliable as well as cumbersome, and the results too variable. According to Brim,[7] the device of Vierordt had been suggested by Herisson in France twenty years previously. But Herisson's apparatus did not have the kymographic attachment; and, failing to become an established instrument, it did not spread the conception of a new clinical procedure. The kymographic technique, though still using direct puncture of the artery and, therefore, restricted to measurement on animals, provided permanent records, permitted more objective observation and, with various modifications, afforded a wide play for physiological study. From the work of this time, especially by Marey,[8] the manometric value of the pressure necessary to obliterate the pulse wave was shown to be a valuable criterion for measurement of the blood pressure. However, a suitable technique and accurate instruments for indirect measurements had not been developed. Sphygmomanometry had not yet become adaptable to man. It began to be so with the device of von Basch,[9] introduced in 1876. von Basch's important contribution consisted of eliminating the direct puncture of the artery and the direct registration of the blood pressure by a column of fluid; instead, he used a bulb or pelotte at the end of a manometer to compress the artery of an extremity so that the wave of pulsation could be gradually eliminated and allowed to return. He introduced two new and fundamental principles; one, the pressure against the extremity and, therefore, the artery could be supplied by a bag containing fluid for compression; and, two, the connection of a mercury manometer to the bag would record the pressure necessary to compress the artery. In accord with these principles, a number of instruments were devised by von Basch, Marey [10] and others. The chief modification by the former was the introduction of a portable metal manometer. More flexibility of use came in 1889 when Potain[11] replaced water with air for compression. His apparatus consisted of a bulb which was placed over the artery and inflated by a second bulb; the pressure was recorded in a portable metal gauge. Again, various modifications, such as by Mosso[12] to register the pressure in the fingers, and by Hürthle,[13] were made in the device, using air for inflation, but the instruments were too complex for general medical use.

Though more easily performed, sphygmomanometry still remained unsatisfactory. The simpler apparatus gave erroneous results; the more complicated ones were too cumbersome. Furthermore, the von Basch-Potain procedure recorded pressure against the more solid tissues of the arm, as well as pressure directly on the artery.

In 1896, Riva-Rocci[14] reported a convenient and more accurate device, on which the modern procedure depends. The method relied upon circular compression of the extremity. In his arrangement, a rubber bag was made to encircle the arm and was inflated by a rubber bulb, pressure from the arm band being registered in the manometer. The artery, therefore, was compressed at right angles from all sides equally, and the application of pressure on non-arterial tissues only was avoided.

Riva-Rocci originally used an armband 5 cm. wide, which was the source of some error. Being narrow, it depressed the tissues at an angle and pressure was recorded against the upper and lower shelf of tissues, as well as against the artery. This source of error was eliminated by the use of a band 12 or 15 cm. wide, the advantages of which were demonstrated by von Recklinghausen[15] in 1901, and a few years later by Stanton,[16] Erlanger,[17] Erlanger and Hooker,[18] and Janeway.[1]

Up to this time, the major criterion for the presence or absence of the pulse wave beyond the constricting band was palpation; palpation gave an accurate enough clue to the systolic or maximum level but did not indicate accurately the diastolic level and, therefore, the mean and pulse pressures. Furthermore, it required a trained sense of touch to appreciate the ebb and flow of the pulse wave. The oscillatory or visual method of taking the blood pressure with the air pressure cuff and manometer lessened the subjective error inherent in the palpatory technique but it was not a procedure adapted to rapid and accurate clinical work. The method depended upon the oscillations transmitted to the fluid in the manometer as the pulse wave came through the compressed artery; the appearance of definite oscillations denoted the first or systolic pressure, the change from large to small oscillations, the diastolic pressure. A variety of instruments, such as by Hill and Barnard,[19] von Recklinghausen,[15] Potain,[20] Erlanger,[17] and Janeway,[1] were soon produced on the Riva-Rocci principle; they relied on the oscillatory as well as the palpatory method and employed either the mercury or the aneroid manometer. By devising an apparatus with a needle pressure gauge primarily for measuring the diastolic pressure shortly after Riva-Rocci's report, Hill and Barnard[19] in England assisted materially in this period of advancement in clinical sphygmomanometry. Also, the more special instrument of Erlanger,[17] employing the kymograph, provided not only accurate but written records of the oscillations of pressure in the air-pressure cuff as it affected the pulse wave. These instruments made possible investigations[18] which established the value of both maximal or systolic and minimal or diastolic readings in the clinical appraisal of blood pressure.

The final step, however, which allowed full scope to, more accurate observation in, and a standardized technique for clinical sphygmomanometry came in 1905 with the introduction of auscultation, devised and reported by Korotkoff.[21]

I have taken particular interest in seeking the original reports of Riva-Rocci and of Korotkoff. Their articles were in journals of limited circulation. They have not been fully reported in English, and bibliographic references are often made inaccurately. I was able to find the original copy of Riva-Rocci's report and that of Korotkoff through the courteous assistance of three gentlemen—Dr. Archibald Malloch, librarian of The New York Academy of Medicine; Mr. Paul North Rice, chief of the Reference Department of the New York Public Library; and Colonel Harold W. Jones, librarian of the Army Medical Library, Washington, D. C. According to the Union List of Serials, the only issue of the journal containing Riva-Rocci's report known to be in libraries in this country is in the Army Medical Library, and the only available issue containing Korotkoff's report is in the Slavonic Division of the New York Public Library.

Riva-Rocci's report was given under the following title: "Un nuovo sfigmomanometro," *Gazetta medical di Torino, 47:* 981-996 (no. 50, Dec. 10); and 1000-1017 (no. 51, Dec. 17), 1896. I should like to give a summary of a translation* of his report.

Riva-Rocci first recorded the purpose of his research on arterial pressure and then set forth the simpler aspects of hydraulics involved. He gave a fairly voluminous review of the literature and described the three types of the von Basch sphygmomanometer available commercially at the time. He preferred the first, or mercurial, model completed in 1881, to the non-mercurial manometer produced in 1883. Riva-Rocci adopted a modification of von Basch's instrument, which was similar to that proposed in 1881 by Rabinowitz, of which Riva-Rocci was not aware. Riva-Rocci's instrument was a "sphygmomanometer likewise based on the principle established by Vierordt and improved on by Marey and von Basch in turn. In other words, it is an instrument affecting manometric measurement of the force necessary to impede the progression of the undulation of the pulse. Sphygmomanometry is then applied to one of the large aortic branches, to the humeral. Since the humeral is the direct continuation of the axillary (since the region contains no collateral large enough to be considered as a branch of the bifurcation), the measurement gives the total charge of a point fairly close to the aorta or, if you like, of the charge of pressure either in the aorta itself (if the left humeral is concerned) or of the brachio-cephalic

* Translations of the articles of Riva-Rocci, Korotkoff, and Krilov were obtained through the facilities of the Library of The New York Academy of Medicine.

trunk (if the right humeral is concerned)." Riva-Rocci considered that his instrument was easy to apply, rapid in action, precise, and innocuous. It was composed of two parts, one for exerting pressure, one for measuring the pressure exerted. The compressor apparatus was represented by a tubular "muff" with walls soft, non-extensible, and impermeable to air. It consisted of a rubber tube 4 or 5 cm. in diameter, lined with a cloth sleeve to prevent undue dilation of the tube. One end of the tube was open, while the other was attached to a piece of metal made in two parts. The patient's arm was tested with this tube plus an insufflator. The intercalation of a manometer revealed the pressure on the "muff" at all times, and hence the pressure exerted on the arm.

Riva-Rocci stated: "The most reliable manometer is still the mercury manometer, but it is necessary to facilitate its reading by adopting a single branch, as in the manometers of Marey and of François Franc, and the original model of von Basch. In order to render the apparatus easier to handle and transport I, too, have adopted the metal manometer. So far, I have been able to obtain only the holosteric kind, since the aneroid kind is of more delicate construction."

In order to prove that his instrument really measured the total charge of the arterial pressure, Riva-Rocci made a number of experimental observations, one series with artificial circulation inside rubber tubes, another with the cadaver arm, and a third with animals.

In the succeeding decade, clinical sphygmomanometry for the first time became a domain of increasing interest and of valuable application in the study of health and of disease in man. Considerable and fairly exact observations and deductions were carried out by physiologists such as von Recklinghausen, Hill, and Erlanger, and by clinicians such as Janeway. But the procedure and its interpretation were confined to a relatively limited medical group.

The opportunity for its wider application was soon offered. In 1905, Korotkoff[21] in Russia reported that by placing a stethoscope over the brachial artery at the elbow below the air-pressure cuff, sounds of the column of blood which flowed into the artery on release of the pressure became audible. Korotkoff's observations were given at a meeting of the Imperial Military Medical Academy in St. Petersburg, December, 1905 and reported in the bulletin of the Academy, "Izvestiya Voenno-meditsinskaie Akademiia," page 365. The original report occupies only a portion of one page in the bulletin, with the title: "On methods of studying blood pressure (from the Clinic of Prof. Feodoreff)." A translation in full reads:

"On the basis of his observation, the speaker came to the conclusion that a perfectly constricted artery, under normal conditions, does not emit any sounds. Taking this fact into consideration, the speaker proposes the sound method for measuring blood pressure on human beings. The sleeve of Riva-Rocci is put on the middle third of the arm; the pressure in this sleeve rises rapidly until the circulation below this sleeve stops completely. At first there are no sounds whatsoever. As the mercury in the manometer drops to a certain height, there appear the first short or faint tones, the appearance of which indicates that part of the pulse wave of the blood stream has passed under the sleeve. Consequently, the reading on the manometer when the first sound appears corresponds to the maximum blood pressure; with the further fall of the mercury in the manometer, there are heard systolic pressure murmurs which become again sounds (secondary). Finally all sounds disappear. The time of the disappearance of the sounds indicates the free passage or flow of the blood stream; in other words, at the moment of the disappearance or fading out of the sounds, the minimum blood pressure in the artery has surpassed the pressure in the sleeve. Consequently, the reading of the manometer at this time corresponds to the minimum blood pressure. Experiments conducted on animals gave positive results. The first sound tones appear (10-12 mm.) sooner than the pulse which (l. ar. radialis) can be felt only after the passage of the major portion of the blood stream."

This was the complete report. It may be of interest to record the discussion at this meeting. It was as follows:

Dr. An. N. Ivanov: How do you explain the origin of the sounds below the sleeve in the beginning and in the end of the examination?

The Speaker (Dr. Korotkoff): In this instance, the pressure in the sleeve is near the minimum pressure in the artery but still in the sleeve it is greater; with the blood stream slipping through, the walls of the vessel separate and give a short, flapping sound.

Dr. Ivanov: What difference did you observe between the minimum and maximum pressure in the brachial artery?

The Speaker: The differences varied greatly, but with a 25-35 mm. norm and higher.

Dr. B. G. Bojovski: If I understood correctly from your very interesting report, you ascribe the origin of the sound phenomena in your simple experiment to purely local causes. The mechanism of the origin of murmurs is understood and does not need any explanation, but as to the development of sounds on the spot I cannot at all agree with you. Your explanation of the origin of sounds below the sleeve as a result of the sharp fluctuation in pressure, with all its appeal, cannot be considered the most important or possibly the only source of the sounds in the circulatory apparatus—the heart. Sounds which can be heard in some more or less large vessels are, no doubt, transmitted along the blood stream, which quite easily conducts these sounds from the closing of the semilunar valves of the aorta. In the nearest to the heart vessels, if they are intact, we hear the systolic tone after the closing of the valves; and in case they are damaged and inadequate, this tone becomes a murmur both in the aorta and in the vessels, for instance in the jugular and in others. Both the tone and the murmur are considered as conducted and not as local. Below the sleeve you cannot hear any sounds when the sleeve compresses the upper arm, probably due to the complete constriction of the brachial artery. In experiments on animals you did not hear anything even when the first drops of blood began to appear from a cut strip of artery with the diminished pressure in the sleeve. The sounds, the murmurs, and then again the sounds you perceive as soon as the flow of the blood begins, so to speak, to become pronounced, i.e., when the blood wave becomes so large that it becomes capable to conduct those sounds which originate in the heart. Your assumption of a local origin of the sounds in the vessels presupposes, one must say, active forces. Apart from the smooth musculature, we don't know of any active force in the blood vessels. And there is too little, or even complete absence, of it in such a vessel as the brachial artery to ascribe to it the origin of sounds in the vessel. Secondly, the time of development of sounds in your experiments coincides with the diastolic of the vessel, and such a state must be regarded as passive and not active. Besides, the blood pressure, by the fluctuations of which you are attempting to explain the reasons for the sounds, is in itself a complex conception. Apart from a certain tension of the blood vessels, blood pressure and its fluctuations in either direction is produced by the energy, by the force of the heart contractions. In view of the above, it seems that, even if there were any foundation for a discussion of the local origin of sounds in the blood vessels, it would still be impossible to deny their

origin in the heart. For the present, I repeat, this is their only source.
The Speaker: First of all, I must say that the sound-tone in this instance is nothing else than the same compression murmur, however of such a short span that it is perceived by the ear as a sound-tone; indeed, the squeezing through of a minimal part of the pulse wave takes place in such a short interval of time (a fraction of 1 second) that it would be amazing if such a forcing would produce a murmur. But I also have reason to assume that the separation of the walls of the constricted vessel also takes part in the production of the sound-tones. Should we allow that the tones originate in the heart and are conducted, then the most favorable conditions for the transmission of these sound-tones should be the absence of any pressure on the pulse wave, i.e., listening to an artery which is not compressed, we should hear the sound-tones; however, under normal conditions this is not observed. Finally, the complete disappearance of the sounds with the complete constriction of the opening in the vessel also speaks against the fact that the sounds are transmitted instead of being of local origin.
Dr. I. P. Shapovalenko: The occurrence of murmurs and sounds under the gradual compression of an artery with a stethoscope has long been known. In your experiment, there was a gradual opening of the compressed artery and the sound phenomena, naturally, occurred in the reverse order, and there was noticed also a weak sound following the appearance of the murmur. Judging from your experiments on a dog, the first sound prior to the murmur appears after the passing of the first drops of blood through the compressed artery, much sooner than the detection of the pulse in the art. radialis and, therefore, with the appearance of the first sound it is possible, of course, to determine the blood pressure more accurately with the Riva-Rocci apparatus than through the pulse.
Dr. N. I. Kulbin: There was no agreement on the theories. Some are inclined to explain the origin of the sounds differently than Dr. Korotkoff. Of course, the subject cannot be considered exhausted. How applicable is your method?
The Speaker: I worked with normal vessels. Possibly in pathological cases these sounds are produced by the vessels themselves."

In issues of the same journal in the next year, 1906, under the title of, "On measuring the blood pressure with the sound method of Korotkoff," there are extensive observations by D. O. Krilov[22] on the origin of the Korotkoff sounds. From numerous experiments, which are fully described and graphically shown, Krilov concluded that the sounds were produced by the fluctuating or centrifugal movement of the blood particles and the simultaneous vibration of the wall of the vessel. In considering the conditions under which these phenomena arose, he discussed but could provide no definite knowledge on the speed of movement of the blood. He described all the influences which affect this speed, namely, the passage of the pulse wave, the degree of vessel compression, the rate of flow and the volume of blood passing through the place of constriction, the height of the pulse wave, the pressure in the vessel, the condition of the walls, and the caliber of the vessel and, to some degree, the specific gravity of the blood. In view of the different combinations of these factors and the variation in their effects, he considered that they are responsible for the variety of sound phenomena observed. All attempts, he stated, to estimate the normal speed of the blood flow were futile; if the Korotkoff method did not permit the measurement of the speed of the blood stream, it had at least made it possible to estimate the fluctuations of this speed, which had diagnostic and prognostic value.

The Korotkoff technique became rapidly accepted and gradually widely used. Impetus to its widespread use came from the experiments of physiologists, from the actual practice and precepts of able clinicians such as Janeway, from instruction in medical schools, and from the requirements of insurance companies. Though considerable study of the last several years has been given to the pathological state of the blood pressure, and though various reports have again been made on the interpretation of the various sounds, especially the diastolic reading, the original remarks of Korotkoff and his colleagues remain tenable, a testimony to the high caliber of their physiological thinking.

Clinical sphygmomanometry, now available in general medicine, became the source of two important contributions to medicine. It increased gradually the knowledge of the state of the blood pressure in health and disease. More importantly, one may believe, it facilitated the general spread of physiological concepts; it helped to develop the appreciation of the historical course of disease by focussing attention on disturbance in function rather than in morphology; and, along with clinical thermometry, it led to more precise and accurate thinking in clinical medicine.

REFERENCES

1. Janeway, T. C. *The clinical study of blood pressure.* New York, Appleton, 1904.
2. Major, R. H. The history of taking the blood pressure. *Ann. M. Hist.* 1930, *2:*47.
3. Hales, S. *Statical essays: containing haemastaticks.* London, W. Innys, R. Manley et al, 1733, v. *2.*
4. Poiseuille, J. L. M. *Recherches sur la force du coeur aortique.* Paris, University Thesis, 1828, p. 23.
5. Ludwig, C. Beiträge zur Kenntniss des Einflusses der Respirationsbewegungen auf den Blutlauf im Aortensysteme, *Arch. f. Anat., Physiol. u. wissensch. Med.,* 1847, *6:*242.
6. Vierordt, K. *Die Lehre vom Arterienpuls in gesunden und kranken Zuständen.* Braunschweig, F. Vieweg u. Sohn, 1855.
7. Brim, C. J. The story of blood-pressure, *M. Life,* 1930, *37:*60.
8. Marey, E. J. Pression et vitesse du sang. In his: *Physiologie expérimentale,* Paris, G. Masson, 1876, v. *2,* p. 307.
9. von Basch, S. Ueber die Messung des Blutdrucks am Menschen, *Ztschr. f. klin. Med.,* 1881, *2:*79.
10. Marey, E. J. Nouvelles recherches sur la mesure manométrique de la pression du sang chez l'homme. In his: *Physiologie expérimentale,* Paris, G. Masson, 1878-79, v. *4,* p. 253.
11. Potain, C. Du sphygmomanomètre et de la mèsure de la pression artérielle chez l'homme, *Arch. de physiol. norm. et path.,* 1889, *1:*556; Détermination expérimentale de la valuer du sphygmomanomètre, *ibid.,* 1890, *2:*300; and Faits nouveaux relatif à la détermination expérimentale de la valeur du sphygmomanomètre, *ibid.,* 1890, *2:*681.
12. Mosso, A. Sphygmomanomètre pour mesurer la pression du sang chez l'homme, *Arch. ital. de biol.,* 1895, *23:* 177.
13. Hürthle, K. Ueber eine Methode zur Registrirung des arteriellen Blutdrucks beim Menschen, *Deutsche med. Wchnschr.,* 1896, *22:*574.
14. Riva-Rocci, S. Un nuovo sfigmomanometro, *Gazz. med. di Torino,* 1896, *47:* 981; 1001.
15. von Recklinghausen, H. Ueber Blutdruckmessung beim Menschen, *Arch. f. exper. Path. u. Pharmakol.,* 1901, *46:* 78.
16. Stanton, W. B. A practical clinical method for determining blood pressure in man, with a discussion of the methods heretofore employed, *Univ. Penn. M. Bull.,* 1902-03, *15:*466.
17. Erlanger, J. A study of the errors involved in the determination of the blood-pressure in man, together with a demonstration of the improvements in the sphygmomanometer suggested thereby, *Am. J. Physiol.,* 1903-4, *10:*xiv; and A new instrument for determining the minimum and maximum blood-pressures in man. *Johns Hopkins Hosp. Rep.,* 1904, *12:*53.
18. Erlanger, J. and Hooker, D. R. An experimental study of blood-pressure and of pulse-pressure in man. *Johns Hopkins Hosp. Rep.,* 1903-4, *12:*145.
19. Hill, L. and Barnard, S. A simple and accurate form of sphygmometer or arterial pressure gauge contrived for clinical use, *Brit. M. J.,* 1897, *2:*904.
20. Potain, C. *La pression artérielle de l'homme a l'état normal et pathologique.* Paris, Masson, 1902.
21. Korotkoff, N. S. On methods of studying blood pressure, *Bull. Imperial Mil. Med. Acad.* (St. Petersburg), 1905, *11:* 365.
22. Krilov, D. O. On measuring the blood pressure by the sound method of Dr. N. S. Korotkoff, *Bull. Imperial Mil. Med. Acad.* (St. Petersburg), 1906, *13:* 113; 221.